# The gas bubble sign—a reliable indicator of laryngeal fractures in hanging on post-mortem CT

Schulze, Katja ; Ebert, Lars C ; Ruder, Thomas D ; Fliss, Barbara ; Poschmann, Sebastian Alexander ; Gascho, Dominic ; Thali, Michael J ; Flach, Patricia M

Abstract: OBJECTIVE: The purpose was to evaluate the presence of gas in the tissue adjacent to the laryngeal structures, "the gas bubble sign", in cases of hanging as a diagnostic indicator of neck trauma. METHODS: In this study, post-mortem CT (PMCT) scans and autopsies of 35 victims of hanging were examined to reveal age-dependent changes, laryngeal fracture, fracture location and the presence of gas. A matched group with cardiac arrest or intoxication was used as controls (n = 35). An autopsy was performed in each case. RESULTS: Incomplete suspension was the most common method in hanging. The thyroid horns (90.5%) were identified as the most vulnerable location for fractures. Laryngeal deformity and dislocation, which was only detected on PMCT, was observed in 57.1% and was concomitant with fractures in 83.3%. Laryngeal fractures are more common with advanced age (>40 years, 88.9%) and less common in younger subjects (<40 years, 29.4%). The gas bubble sign with regard to laryngeal fractures yielded a sensitivity of 79.2%, a positive predictive value of 95%, a specificity of 90.9%, a negative predictive value of 34.5% and an accuracy of 83%. CONCLUSION: The complex evaluation of the larynx is profoundly supported by PMCT and the detection of the gas bubble sign as a diagnostic indicator of neck trauma. This relevant diagnostic finding might aid in not only post-mortem cases but also clinical cases, for patients who survive an assault to the neck. Advances in knowledge: (1) The gas bubble sign is a diagnostic indicator of neck trauma in not putrefied bodies. (2) PMCT supports evaluation of trauma to the neck in hanging tremendously. (3) The diagnostic finding of gas located at the laryngeal structures may not only aid in post-mortem cases but also clinical cases of people who survive an assault to the neck.

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## FULL PAPER

# The gas bubble sign—a reliable indicator of laryngeal fractures in hanging on post-mortem CT

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**Objective:** The purpose was to evaluate the presence of gas in the tissue adjacent to the laryngeal structures, "the gas bubble sign", in cases of hanging as a diagnostic indicator of neck trauma.
**Methods:** In this study, post-mortem CT (PMCT) scans and autopsies of 35 victims of hanging were examined to reveal age-dependent changes, laryngeal fracture, fracture location and the presence of gas. A matched group with cardiac arrest or intoxication was used as controls ($n$ = 35). An autopsy was performed in each case.
**Results:** Incomplete suspension was the most common method in hanging. The thyroid horns (90.5%) were identified as the most vulnerable location for fractures. Laryngeal deformity and dislocation, which was only detected on PMCT, was observed in 57.1% and was concomitant with fractures in 83.3%. Laryngeal fractures are more common with advanced age (>40 years, 88.9%) and less common in younger subjects (<40 years, 29.4%). The gas bubble sign with regard to laryngeal fractures yielded a sensitivity of 79.2%, a positive predictive value of 95%, a specificity of 90.9%, a negative predictive value of 34.5% and an accuracy of 83%.
**Conclusion:** The complex evaluation of the larynx is profoundly supported by PMCT and the detection of the gas bubble sign as a diagnostic indicator of neck trauma. This relevant diagnostic finding might aid in not only post-mortem cases but also clinical cases, for patients who survive an assault to the neck.
**Advances in knowledge:** (1) The gas bubble sign is a diagnostic indicator of neck trauma in not putrefied bodies. (2) PMCT supports evaluation of trauma to the neck in hanging tremendously. (3) The diagnostic finding of gas located at the laryngeal structures may not only aid in post-mortem cases but also clinical cases of people who survive an assault to the neck.

## INTRODUCTION

For the year 2009, the National Center for Injury Prevention and Disease Control's National Violent Death Reporting System reported 2644 deaths annually in North America from "hanging, strangulation, and suffocation" for 16.1% of all violent deaths (rates: 9.8, 3.8 and 3.2 per 100,000 population, respectively).[1] Hence, after firearms (48.8%) and poisoning (19.1%), hanging represents the third most common method of violent deaths in the United States of America.[1]

Autopsy with the dissection of the larynx is the established gold standard for the forensic assessment. However, autopsy of the laryngeal structures is complex and requires special preparation.[2,3] The strap muscles need to be neatly dissected, and the cartilage and/or ossified laryngeal structures must be detached from the soft tissue to precisely expose fractures, despite haemorrhage. If not performed properly, false results can occur.[4]

The mechanism as cause of death in hanging is complex, and it might appear independently based on one pathophysiological mechanism or combined. There are three major pathophysiological theories described: (1) venous obstruction with cerebral stagnation, followed by hypoxia and final arterial obstruction; (2) arterial spasm in carotid pressure with low blood flow and even collapse; (3) vagal collapse with reflex cardiac arrest.[2,4] In addition, mechanical airway compression or even spinal cord brainstem disruption can occur.[2,4] According to the literature, reflex cardiac arrest and carotid occlusion might be more prevalent in hanging than in other cases of asphyxia.[2] However, the form of suspension (complete or incomplete) and the

location of the noose play a crucial role in determination of the cause of death. Incomplete suspension (lower body parts touch the ground) is described as being common. In complete suspension, the body hangs freely. Most hangings are suicidal; accidental hangings are uncommon, and homicidal hangings are currently very rare.[4]

Laryngeal fractures are significant indicators in proving the applied pressure to the neck and are not merely relevant in terms of threat to life.[2] Post-mortem CT (PMCT) has already proven to be paramount in the entire evaluation of the laryngeal structures and enhances forensic evaluation in cases with trauma to the neck.[5] In clinical practice, CT is the gold standard for the evaluation of the osseous and cartilaginous structures of the neck, whereas magnetic resonance is used to evaluate the soft tissue.[6–11] PMCT adds information of bony and cartilaginous lesions to the evaluation of the neck, as already described by the literature.[5,8] Numerous anatomical variants of the larynx might pose problems and hamper the evaluation of the neck during autopsy and, to a certain degree, during PMCT.[12]

The occurrence of a vacuum phenomenon (also called minute gas) as an anatomical entity is well known in radiological imaging.[13] It is most commonly observed in degenerative joint disease, but also in abscess, osteomyelitis, multiple myeloma, iatrogenic, joint effusion, bone fracture, Schmorl's nodes and trauma such as ligament tears.[14] However, the underlying causes remain under debate.[14,15] The theory is based on the hypothesis that enclosed tissue space is able to expand as a rebound phenomenon after an external impact, and the volume within the enclosed space will increase.[14,15] While the volume expands, the pressure within the space will decrease.[14,15] Hence, decreased solubility allows gas to leave a solution and to be detectable as a vacuum phenomenon.[14,15] Studies also describe that the vacuum phenomenon is sometimes recognized near a traumatized lesion and is most often observed in female cases.[13] Omori et al describe that the greatest number of vacuum phenomenon cases were located at or near rib fractures, followed by joint spaces that had experienced a traumatic impact.[13]

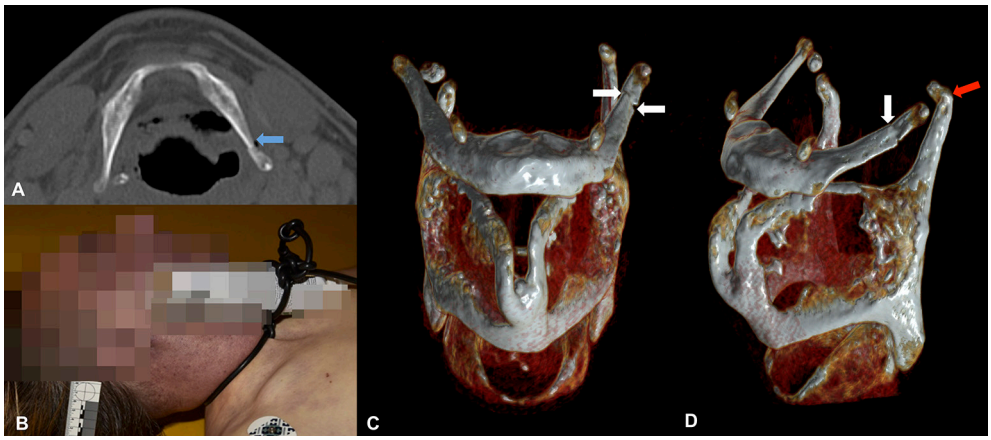
In cases of hangings the authors observed gas bubbles in the tissue adjacent to the laryngeal structures when fractures were present (Figure 1). Hence, the purpose of this study was to evaluate the presence of gas in the tissue adjacent to the laryngeal structures, "the gas bubble sign", in cases of hanging as a diagnostic indicator for neck trauma.

## METHODS AND MATERIALS

### Post-mortem CT

The responsible justice department approved PMCT examination and mandated forensic autopsy. Each corpse received a full-body PMCT scan using a dual-source 128-slice scanner (SOMATOM Flash Definition, Siemens Medical Solutions, Forchheim, Germany) with standard scan parameters at a 120 kVp tube voltage with automated dose modulation (800 reference mAs), with parameters according to the literature.[16] Reconstructions were made in a soft tissue window with a soft kernel (H31) and bone window with a hard kernel (H60) in an adjusted field of view. Image analysis of the laryngeal skeletal structures was conducted on all three planes (axial, coronal and sagittal) in a hard kernel with bone window (slice thickness 0.6 mm). The bone window pre-set (width 1500, centre 450) was manually adjusted to a broader window (width 3000, centre 750) for a better assessment of subtle bony structures and gas bubbles. Special attention was paid to the sagittal reconstruction of the neck because fractures of the greater horn of the hyoid and the upper horn of the thyroid are more easily assessable. Finally,

Figure 1. This 40-year-old male exhibits a distinct fracture of the hyoid with the detection of the gas bubble sign [Image (a) arrow] adjacent to the greater horn of the left hyoid bone (white arrows) in the soft tissue. (a) Axial slice in a hard kernel and adjusted bone window. Note the subtle fracture line of the left-sided greater horn of the hyoid bone with the adjacent gas bubble ( arrow) within the soft tissue in close proximity to the fracture line. (b) Photograph of the suicide. The deceased strangled himself with an electricity cable by using an aerosol can as strangling amplifier. (c) three-dimensional (3D) volume rendering technique, anterior view, with a distinct depiction of the left-sided fracture of the hyoid bone (white arrows). Note the natural joint on the right side of the upper horn of the thyroid (also observed in a and d). (d) 3D volume rendering technique, left lateral view, with the depiction of the hyoid fracture (white arrow) as well as the anterior medially displaced fracture of the ipsilateral thyroid upper horn (Image D arrow pointing on the upper horn).



validation of laryngeal fractures and assessment of deformity and dislocation of the thyrohyoidal membrane and its configuration were performed with three-dimensional (3D) volume rendered reconstructions.

Primary image reviews and 3D reconstructions were performed by using a CT workstation (Leonardo, Siemens, Medical Solutions, Forchheim, Germany). For radiological assessment, a multimodality workstation was used (Syngo via, v. VB10A, Siemens, Medical Solutions, Erlangen, Germany). Case-based specific image reconstructions were additionally performed by cinematic rendering software with a physically based rendering technique (Research platform, Cinematic Rendering, Siemens CT 1.0.0, Frontier Prototype Store, Syngo via, v. VB10A, Siemens, Medical Solutions, Erlangen, Germany). Radiological analysis and reporting was performed by a forensic experienced board-certified radiologist.

### Radiological assessment

Assessment of the larynx included the location of fractures (hyoid with the lesser and greater cornu, thyroid cartilage and the upper and lower horns, cricoid cartilage and dehiscence of arytenoid cartilage from the cricoid cartilage), the presence of the "gas bubble sign" within the adjacent tissue or the bone/cartilage itself and deformity and/or dislocation of the thyrohyoidal membrane and the hyoid and/or thyroid cartilage (LDD). Both the strangulation group and the control group were evaluated regarding the presence of gas within the adjacent laryngeal structures, fractures and laryngeal deformity or dislocation (LDD).

For the gas bubble sign with regard to fractures sensitivity, the positive predictive value (PPV), specificity, negative predictive value (NPV) and accuracy were calculated. The mode of suspension was assessed in the strangulation group. Additionally, two age-dependent groups were created: a group below 40 years and a group over 40 years of age. Those were assessed for the presence of fractures. The age grouping of the strangulation cases was chosen based on literature distinguishing younger subjects as less than 40 years from older subjects as a cut-off value.[2,17]

The image assessment was performed in consensus with the autopsy findings; the forensic pathologists were informed about the relevant imaging findings prior to autopsy. Specific findings such as LDD, arytenoid and cricoid lesions were separately evaluated on PMCT and autopsy.

### Autopsy

Conventional autopsy included dissection of the three body cavities (skull, thorax and abdomen) as well as preparation of the larynx and was performed in each evaluated case. The determination of laryngeal fractures was based on either adjacent soft tissue haemorrhage and/or hypermobility of the laryngeal structures, particularly the horns of the thyroid and hyoid. Subtle dissection of the surrounding tissue—rarely by maceration of the laryngeal skeleton—histology and toxicology were not consistently performed. Autopsy was performed by a board-certified forensic pathologist and a resident.

### Study collective

#### *Strangulation group*

All hanging cases referred to the Institute of Forensic Medicine between 2013 and early 2016 were reviewed. The retrospective analysis was performed for a 3-year period. The inclusion criteria were no radiological signs of decomposition, no thermal injuries, age older than 18 years and the only cause of death was strangulation by hanging. The final study population was $n$ = 35. The age ranged from 19 to 76 years (mean 39.8 years) in 24 males and 11 females. The case collective ($n$ = 35) died exclusively from asphyxia due to strangulation by hanging with suicide as the manner of death. The strangulation tool was mostly a rope ($n$ = 9), followed by electricity cable ($n$ = 8), shoestrings ($n$ = 5), shawl ($n$ = 3), belt ($n$ = 2) and clothes ($n$ = 2). A tie, plastic clothes line, hand towel, bike lock, shower curtain and brace were each used once. Of the entire study population 26/35 (74.3%) did not undergo any resuscitation attempts, 4/35 (11.4%) did receive cardio-pulmonary resuscitation (CPR) by laypeople and 5/35 (14.3%) underwent professional unsuccessful CPR. In total only 9/35 (25.7%) subjects received any kind of CPR (professional or laypeople CPR). The interval between time of death to PMCT scan ranged from 5.5 to 262 h (mean: 33 h). The time to autopsy interval ranged from 12 to 286 h (mean: 41 h). One case had a long post-mortem interval because this person was found hanging in a barn in the winter and therefore, no signs of decomposition were visible.

#### *Control group*

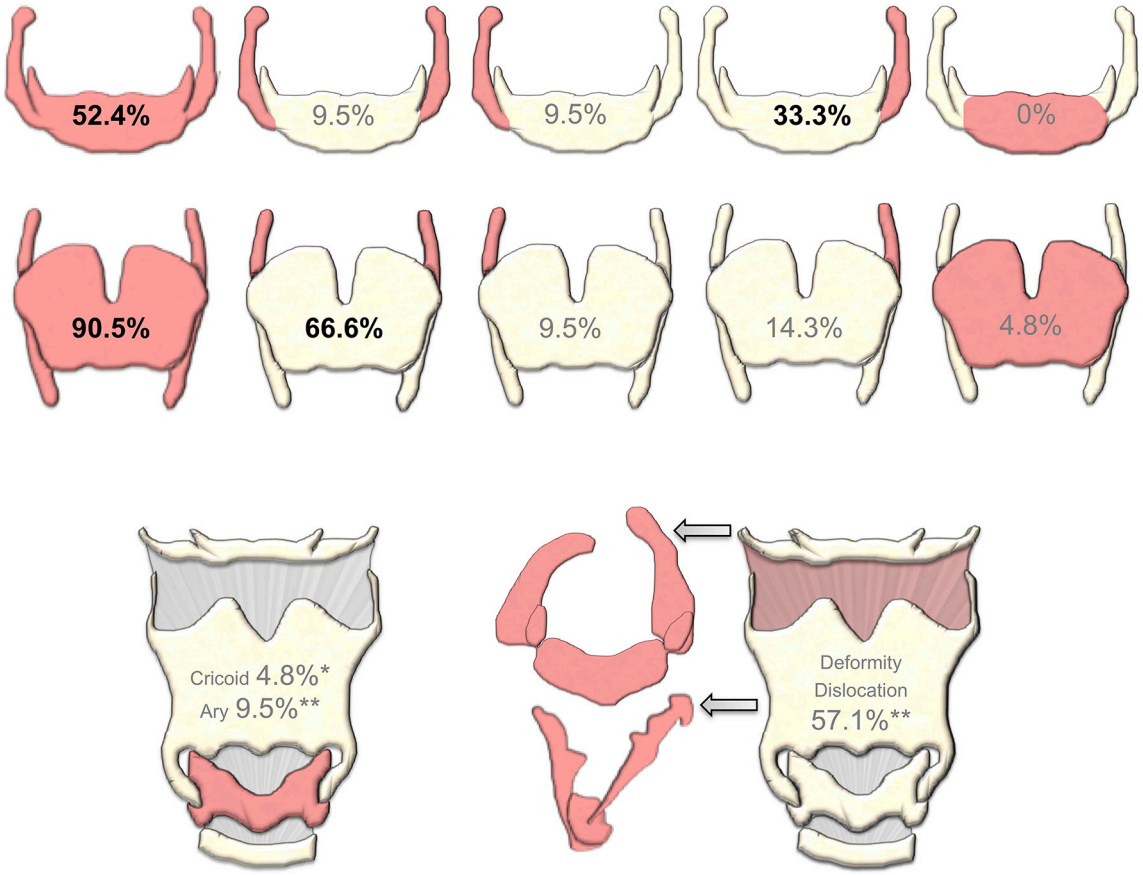
The control group ($n$ = 35) met the same exclusion criteria as the above strangulation group. Additionally, no fractures of the larynx or trauma to the neck were present. The retrospective analysis was performed in a 1.5-year period. The control group was matched by sex and age. The age range was fully matched in 14 cases; a 1 year deviation was present in 11 cases, a 2 year deviation was present in in 8 cases, and a 5 year deviation was present in 2 cases. The age ranged from 17 to 77 years (mean: 40.6 years, median 36 years). The sex was matched in each case (24 males, 11 females). The cause of death was either cardiac arrest ($n$ = 20) or intoxication ($n$ = 15). None of the control cases exhibited relevant signs of trauma. The majority 22/35 (62.9%) did not undergo any resuscitation attempts. However, still 13/35 (37.1%) control subjects received unsuccessful professional CPR. The manner of death was predominantly natural death ($n$ = 18), followed by suicide *vs* accident ($n$ = 9), accident ($n$ = 5), suicide ($n$ = 2) and one case of criminal death. The interval between time of death to PMCT scan ranged from 4.5 to 67 h (mean: 26 h, median: 15 h). The time to autopsy interval ranged from 6.5 to 74 h (mean: 35.5 h, median 26.5 h).

## RESULTS

### Mode of suspension

Incomplete suspension was defined as parts of the body such as toes or feet touching the ground whereas complete hanging is defined by no body part touching the ground (Ref: DiMaio). The majority of cases (65%) had an incomplete mode of suspension ($n$ = 23/35). Typical mode of suspension is defined by the position of the knot behind the ear whereas in an atypical mode of suspension the knot lies in front of the ear.[18] An incomplete,

Figure 2. An illustrated overview of the location of fractures and the percentages. The fracture site is coloured in red with an anterior view. Percentages marked with one asterisk were only detected during autopsy. Percentages marked by two asterisks were only observed on PMCT. PMCT, post-mortem CT.




atypical mode of suspension ($n$ = 14/35) was predominant, followed by incomplete, typical ($n$ = 9/35), then complete, typical ($n$ = 5/35) and finally, complete, atypical ($n$ = 4/35). Three cases could not be determined.

## Laryngeal fractures

The total percentage of cases with laryngeal fractures in the hanging group was 60%, $n$ = 21/35. None of the cases in the control group exhibited any fractures of the laryngeal skeleton.

In total, 52.4% ($n$ = 11) of fractures involved the greater horn of the hyoid (bilateral 9.5%, $n$ = 2; right side 9.5%, $n$ = 2; left side 33.3%, $n$ = 7) (Figures 2 and 2). The thyroid exhibited fractures in 90.5%, $n$ = 19 (bilateral upper horns 66.6%, $n$ = 14; right side 9.5%, $n$ = 2; left side 14.3%, $n$ = 3; laryngeal prominence 4.8%, $n$ = 1) (Figures 2–4). A cricoid lesion was observed as haemorrhage within the cartilage during autopsy in only one case (4.8%), and dehiscence of the arytenoid cartilage were detected only by PMCT in 9.5% ($n$ = 2) (Figure 2).

## Laryngeal deformity and dislocation

PMCT revealed LDD in 57.1% ($n$ = 12), which were not observed in autopsy Figure 2. All 12 cases displayed LDD, but only 3 cases (25%) exhibited an additional deformity of the hyoid, and only 1 (8.3%) of the thyroid cartilage itself (Figure 5). The age in these 12 cases with LDD ranged from 20 to 76 years (mean 43.8 years, median 43.5 years). Only 2 (16.7%) of these 12 cases also presented without laryngeal fractures, meaning that 10 cases (83.3%) were positive for fractures as well (Figure 4).

In the remaining patients ($n$ = 23) with no LDD, the age ranged from 19 to 76 years (mean 37.8 years, median 32 years). In this non-deformity group, 11 cases (47.8%) were positive for fractures, and 12 cases (52.2%) did not have fractures.

## Age-related grouping and fractures

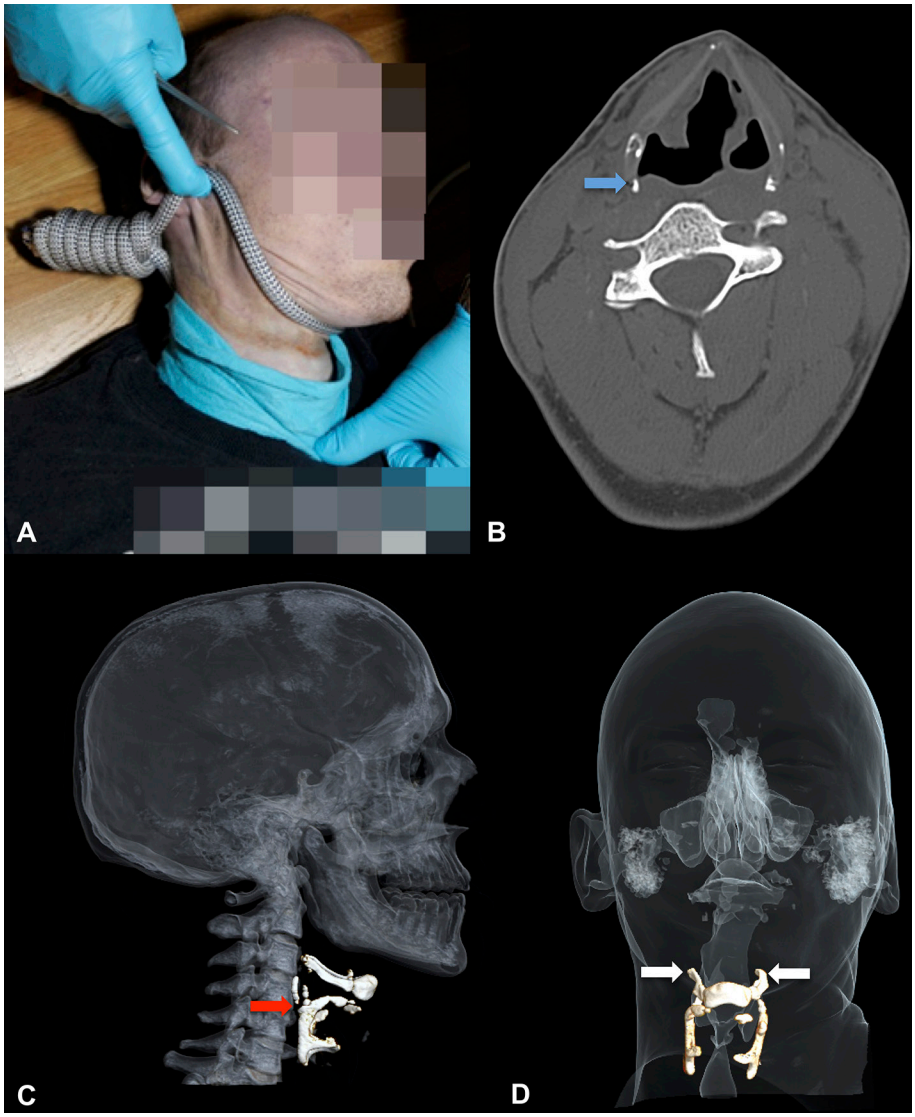
The younger group below 40 years of age ($n$ = 17, range 19 to 38 years, mean 26.4 years, median 26 years) included 5 cases (29.4%) with fractures and 12 cases (70.6%) without fracture.

The older study population over 40 years ($n$ = 18, range 40–76 years, mean 52.5 years, median 50 years) included 16 cases (88.9%) with laryngeal fractures and only 2 cases (11.1%) with no fracture (Figure 3).

## Gas bubble sign

For the presence of the gas bubble sign with regard to laryngeal fractures, there were 19 true positive and 10 true negative cases (Figures 1 and 3–5). One ca se was assessed as a false positive (meaning no gas, but fracture) and five cases were assessed as

Figure 3. (a) This 24-year-old male was found dead with a rope as strangling tool. The mode of suspension was atypical and incomplete. (b) Axial view at the level of the thyroid cartilage, which is partially ossified. Note the gas bubble sign (blue arrow) adjacent to the transition from the right superior thyroid tubercle to the upper horn due to a fracture of the ipsilateral thyroid upper horn. Additionally, this case exhibited a tiny internal laryngocele on the left , which should not be mistaken for the gas bubble sign. (c) three-dimensional (3D) volume rendering technique, right lateral view, of the broken upper horn of the thyroid ( arrow). (d) 3D volume rendering technique, anterior view, with a fusion of the laryngeal skeleton and air-containing structures. Note the misplacement of both greater horns of the hyoid bone correlating to fractures (white arrows). The thyroid is slightly misplaced against the hyoid due to LDD. This case presented with LDD and concomitant laryngeal fractures. LDD, laryngeal deformity or dislocation.

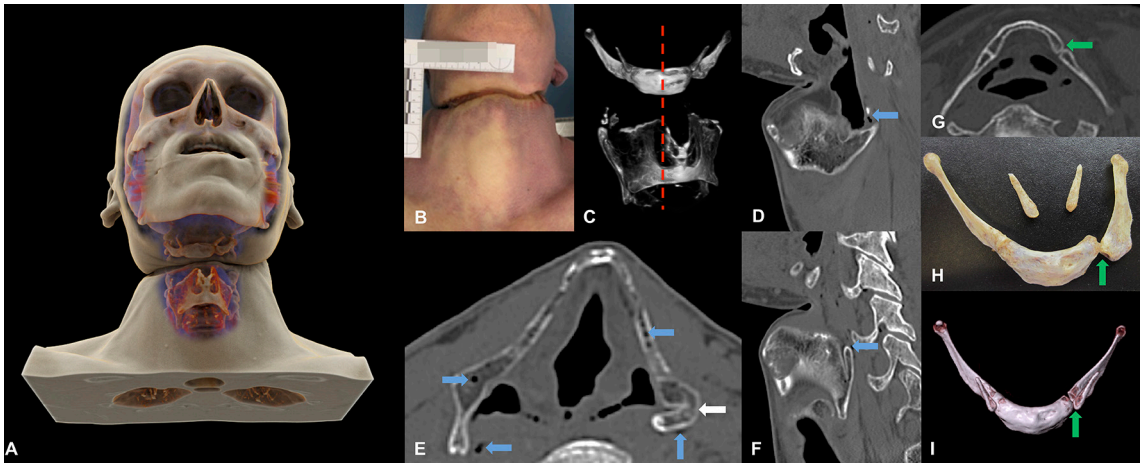



false negatives (meaning gas present, but no fracture). The precision for the gas bubble sign is reflected by a very high PPV of 95%, with a high accuracy of 83%. The sensitivity was calculated as 79.2%. The specificity was high at 90.9%. The NPV was moderate at 34.5%. None of the cases in the control group displayed any gas within the laryngeal and its adjacent soft tissue (PPV 0%, accuracy 100%, sensitivity 0%, specificity 100%, NPV 100%).

## DISCUSSION

This study found that a positive gas bubble sign is highly suggestive of laryngeal fractures in hanging cases. The PPV was 95%, and the overall accuracy was 83%, indicating that the gas bubble sign is a valid diagnostic indicator for trauma to the neck during hanging in not putrefied cases. The sensitivity for the gas bubble sign was calculated at 79.2%, indicating that the gas bubble sign avoided false negatives quite well but still poses no flawless diagnostic indicator. In turn, this allows for the conclusion that detecting the gas bubble sign on PMCT is associated with a high probability that fractures of the laryngeal skeleton will be present, and as shown in the control group, the opposite is also concluded. The diagnostic relevance of the gas bubble sign is strengthened by the fact that none of the cases from the control group exhibited this finding at the laryngeal structures.

Figure 4. (a) Cinematic rendering technique visualizing the strangling mark and the laryngeal skeleton. The noose of the strangling instrument (rope) was placed below the hyoid bone at the level of the upper horns of the thyroid. (b) External inspection photograph of the strangling mark in a 50-year-old male. (c) three-dimensional (3D) volume rendering technique, anterior view, of the hyoid and thyroid displaying LDD. The red line indicates the midline of the hyoid bone. (d) Sagittal view of the upper horn of the ossified thyroid cartilage exhibiting distinct gas bubbles (blue arrow) at the fracture site of the upper horn on the right. (e) Axial view, angulated to the ossified thyroid cartilage and its upper horns on both sides. The left side is fractured and tilted medially (white arrow), and there is a fracture at the base of the right upper horn. The arrows indicate the gas bubbles within the ossified cartilage and in the adjacent soft tissue. (f) Sagittal view of the upper horn of the ossified thyroid cartilage exhibiting distinct gas bubbles (arrow) at the fracture site of the displaced upper horn on the left. (g) Axial view of the intact hyoid bone as it appears *in situ* on PMCT. The left side shows a natural fibrocartilage joint ( arrow) with sclerosed and round borders, and the right side is fused. No fracture assessable. (h) Macerated specimen of the hyoid bone, anterior view, displaying the same finding as PMCT. After maceration, the fibrocartilage joint (arrow) and both lesser horns are detached. (i) 3D volume rendering technique, anterior view of the hyoid bone with the *in situ* depiction of the variant with one fused side and a fibrocartilage joint on the left (arrow). LDD, laryngeal deformity or dislocation; PMCT, post-mortem CT.




Limitations of this study are that decomposed bodies will not allow for the usage of the gas bubble sign as diagnostic indicator of neck trauma as well as cases with soft tissue emphysema.

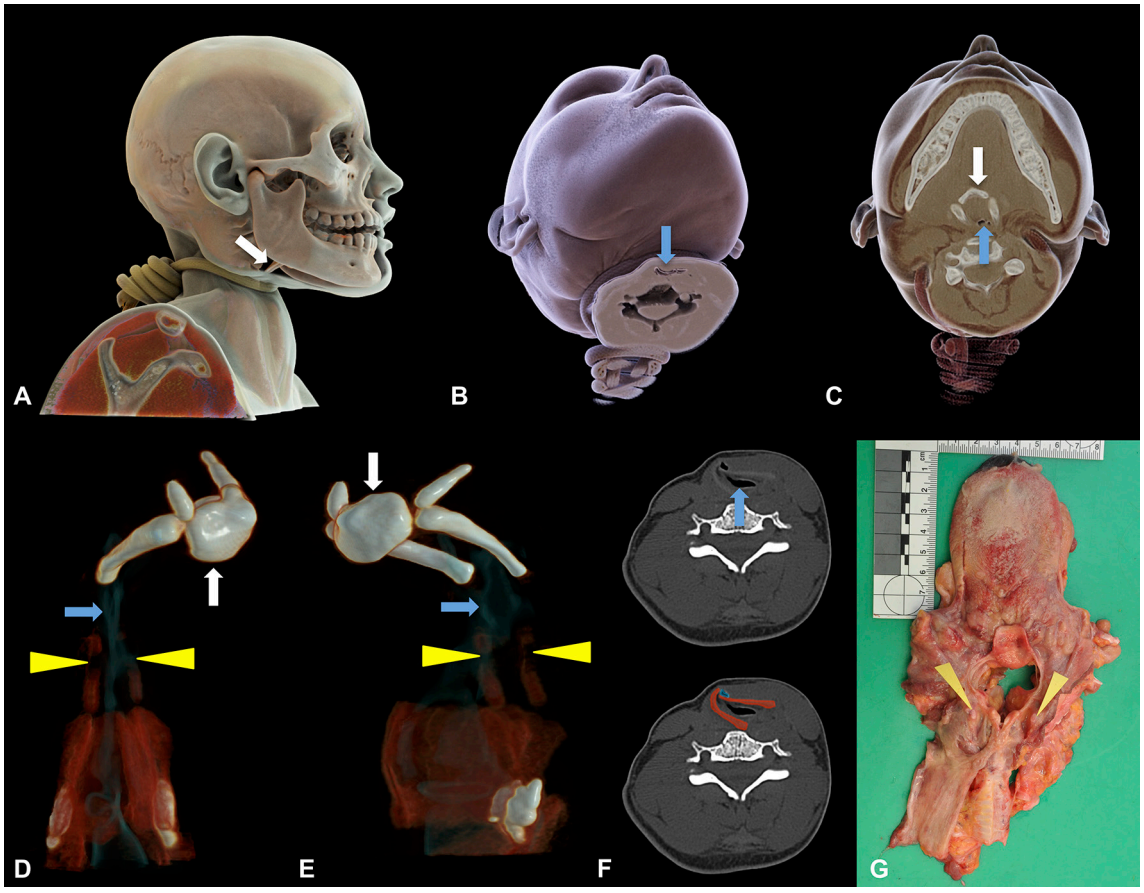
The occurrence of the vacuum phenomenon (minute gas) in laryngeal fractures may have the same aetiology as described in studies detecting gas bubbles near a traumatized lesion.[15] Gas adjacent to fractured laryngeal structures was not described in clinical reviews or studies. In the post-mortem collective, the gas bubble sign was a highly diagnostic indicator for fractures of the larynx. Nichols et al state that cervical near-hangings are not rare, but yet received little attention in trauma literature. The authors gained increasing case numbers with near-hanging trauma and do recommend PCT of the head and neck in those cases.[19] In living patients, this finding remains to be validated and might aid in the future in detection of laryngeal trauma of surviving cases.

This study corroborates that CPR had no influence on the occurrence of the gas bubble sign at the laryngeal structures. The control group included more cases with CPR 37.1% than the study population that included only 25.7% of the subjects with CPR (professional 14.3% or laypeople 11.4% CPR).

It is reported that manual strangulation can lead to lateral pressure on the horns of the hyoid and thyroid with an inward and medial displacement—either by direct impact or by pressure on the thyrohyoid membrane[2] (Figure 6). In younger subjects, the horns are still flexible and might return in their prior position when the pressure on the neck is released.[2] Hence, PMCT scanning with the injuring tool still in place is advisable, especially in young adults whose joints are still mobile and not-yet-fully-ossified (Figure 5). Therefore, imaging with the strangling tool in place might facilitate the entire assessment of the dislocation and misplacement of the laryngeal structures as well as the degree of airway compression (Figure 5). If the strangling tool has already been removed, PMCT imaging might still allow for the assessment of dislocation of the larynx without the ligature because the larynx remains unaltered and *in situ* (other than in autopsy).

This study did show that LDD was not detected during autopsy—potentially due to the dissection of adjacent tissue and inevitable mechanic manipulation during autopsy (Figure 4). Additionally, the thyrohyoid ligament is not always dissected during autopsy, which might lead to a splinting effect of a broken horn with an impeded assessment of fractures. This finding of LDD could additionally be relevant for the assessment of surviving victims in clinical practice undergoing antemortem CTscanning in the emergency room for laryngeal assessment as a first-line examination prior to potentially subsequent antemortem MRI.[6,7,9–11] Pathology in living patients might not always be derived from laryngeal fractures but rather from alterations of the larynx with dislocation or deformity of the larynx due to compression of its structures. Still, (forensic) AMMR for clinical patients is currently the advised method to evaluate the soft tissue and the deep vasculature and nerve sheath as well as subtle pathologies located within the soft tissue, *e.g.* haemorrhage.[9–11,20,21]

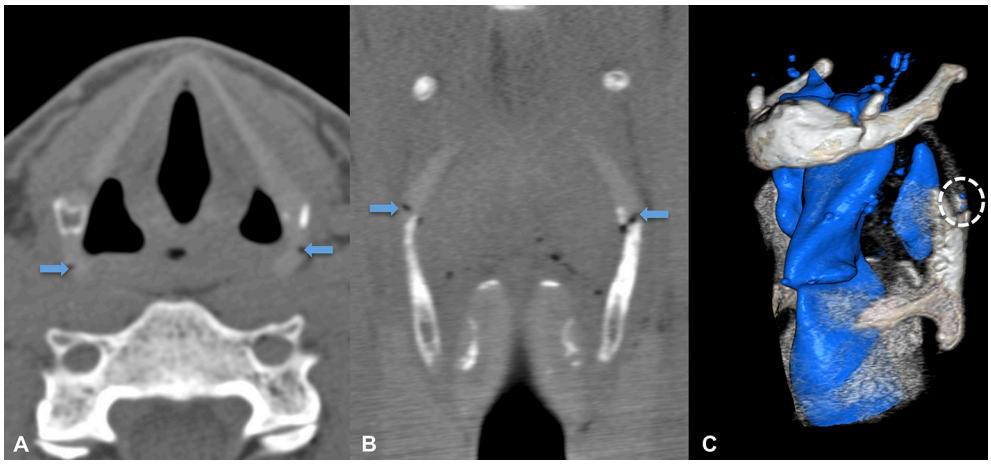
Figure 5. (a) Cinematic rendering technique of the head and neck of a 20-year-old female with the strangling rope left in place. The hyoid bone is barely above the noose and shows a caudally tilted orientation with compression (white arrow). (b) Cinematic rendering technique virtually cut at the level of the thyroid. Note the massive airway and laryngeal compression (blue arrow) with a slit-like laryngopharynx due to the tightened noose around the neck. With the strangling tool still in place, such findings are easily visualized by PMCT *in situ*, but not by autopsy. (c) Cinematic rendering technique virtually cut at the level of the displaced hyoid (white arrow). The airways at this level are at a maximum level of compression (arrow) because the noose of the rope is placed directly at this level. (d) three-dimensional (3D) volume rendering technique, right lateral view, showing the isolated displaced hyoid bone (white arrow), the slit-like airways ( arrow) and the fractures of the not-yet-fully-ossified thyroid (located at the laryngeal prominence) and its upper horns (arrowhead). (e) 3D volume rendering technique, left lateral view, showing the isolated displaced hyoid bone (white arrow), the slit-like airways (arrow) and the fractures of the not-yet-fully-ossified thyroid (located at the laryngeal prominence) and its upper horns (arrowheads). (f) Axial slice of the thyroid cartilage with the narrowed airways (b arrow, upper image). Note the gas bubble anterior to the laryngeal prominence (highlighted , lower image) and anterior to the median thyroid fracture (the thyroid cartilage is highlighted). (g) Autopsy specimen. Both arrowheads mark the fractured upper horns of the thyroid. PMCT, post-mortem CT.




A recent study by Kempter et al showed that 75% of their investigated cases were concordant in autopsy and PMCT, but 25% were only seen on PMCT, stating that PMCT may serve in combination with a thorough external examination and profound incident-scene investigation as a useful decision-making tool for further examinations, *i.e.* autopsy.This statement is supported by the results of the underlying study.

60% in the hanging group presented with laryngeal fractures; mainly located at the thyroid. The findings of PMCT were confirmed by autopsy, although some cases had to be re-assessed during autopsy to look for PMCT findings detected prior to autopsy and order to confirm them. This poses a bias to this study. Literature describes fractures of neck structures with 47.5% and also more common in older victims and males. However, in this study PMCT was able to provide more information, which may have led to slightly a higher percentage of fractures of the laryngeal structures.[22] Another limitation to the present study was that subjects with progressed decomposition, soft tissue emphysema and thermal injuries, and even those with fierce puncture attempts for a central line in agonal or pre-terminal emergency situations, had to be excluded. Although decompositional changes exhibit another gas pattern as the gas bubble sign, advanced putrefaction can obscure this finding. The literature proposes the analysis of subtle laryngeal fractures in decomposed bodies by microfocus CT (micro-CT) in combination with PMCT as an alternative to PMCT alone, if findings are uncertain.[23, 24] In cases of decomposition, this might allow for an

Figure 6. (a) Axial slice at the level of the thyroid cartilage and the base of both upper horns. This 28-year-old male committed suicide with an atypical, incomplete mode of suspension and sustained bilateral fractures of the thyroidal upper horns. Distinct gas bubbles are observed at the location of the fracture ( arrows). (b) Coronal view of both upper horns of the thyroid cartilage. Note the gas bubbles at the location of the fracture ( arrows). The edges of acute fractures are sharp and not sclerosed and round, as in Figure 4g. (c) 3-D volume rendering technique, left anterior view, displaying gas-filled structures in blue in correlation with the laryngeal skeleton. The gas bubbles are white encircled. Tiny gas bubbles are observed at the fracture site at the base of the not-yet-fully-ossified upper horn (on the lef.




alternative to detect laryngeal fractures. Currently, the laryngeal structures must be removed from the body to fit in the gantry of a micro-CT. Therefore, this *ex situ* scanning is a cumbersome and invasive method. In addition, the removal of the laryngeal package leads to inevitable air inclusion within the soft tissue and the detection of the gas bubble sign and would therefore no longer be an option as a diagnostic indicator.

In strangulation, the literature describes incomplete suspension as common, and this could be confirmed in 65% of the cases based on this study.[4] Additionally, an atypical mode of suspension was more common than a typical mode. According to the literature, most hangings are suicidal, which was likewise in the investigated case collective.[4]

The thyroid horns are described as a more vulnerable location than the hyoid for violence to the neck, and this was affirmed by the underlying study in which almost 91% of the fractures were located there and were mostly bilateral, but dominated on the left side[4, 25, 26] (Figure 2). Additionally, this study proved that fractures are more common with advancing age and less common in younger subjects. The study population >40 years had laryngeal fractures in almost 89%, whereas the younger study population <40 years exhibited laryngeal fractures only in approximately 29% (Figure 4). The literature also describes that the geometry of the horns of the thyroid cartilage might be a significant diagnostic factor in traumatic neck injury. With advancing age, the angulation of the superior horn to the posterior branch of the thyroid decreases, and the inferior horn in males protrudes significantly more anteriorly than in females.[26] This might affect the age-dependent occurrence of fractures as well as the progressing thyroidal calcification with age.[17, 26] The superior horns of the thyroid as the most common fracture sites are reported as being associated with a ligature positioned on the thyrohyoid membrane or thyroid laminae[26] (Figure 5). A sex-based assessment of the occurrence of fractures as well as the position of the ligature with regards to fractures was not performed in the underlying study.

This study also showed that PMCT is superior to autopsy with regard to LDD. This finding was observed in more than half of the strangulation cases, but not reported in autopsy. This study revealed that LDD did not correlate with the subject's age. Additionally, LDD was present in the majority of cases (83%) when concomitant fractures were present (Figure 4).

For decades, conventional, two-dimensional radiography has been established for the assessment and identification of fractures and natural joints of the hyoid and thyroid.[2, 4, 27] PMCT is still a fairly new tool for post-mortem imaging, but certainly allows for a far more detailed, 3D assessment of the larynx; therefore, it should be used as an essential tool, at least for supplemental information to forensic autopsy.[21, 28] In particular, because it adds information that would be otherwise lost at autopsy, it might even prove to be superior in some aspects for the evaluation of the larynx.

However, any investigator, either with imaging or during autopsy, must be aware of the multitude of anatomical variants, natural joints, tritiate cartilage or fusion of parts of the larynx.[2, 27] PMCT allows for the depiction of round, sclerosed borders in cases of anatomical variants and natural joints; it also allows for the detection of sharp borders, as observed in acute fractures, and the anatomical location of the larynx *in situ* for an easier and faster discrimination between variants and pathology (Figures 4 and 6). This is supported by the gas bubble sign as a diagnostic tool to detect laryngeal trauma and therefore aids in the evaluation of injuries to the neck. Regarding variants of the laryngeal skeleton, particularly the thyroid cartilage, the accurate evaluation of the discrimination between fatty osseous or cartilaginous

changes *vs* gas within the thyroid must be performed, *e.g.* by Hounsfield (HU) measurements. Fatty alterations of the thyroid cartilage were occasionally observed at the transition from the main body to the superior horn. Caution must also be taken to avoid misdiagnosing a partial volume of potentially air-containing structures such as the epiglottic vallecula, piriform fossa, internal laryngocele, oesophagus, or vacuum phenomenon at natural joints *vs* the gas bubble sign (Figure 3).

A radiological read-out should be performed with a baseline assessment of the larynx in the axial and coronal planes and, most importantly, the sagittal plane. This in turn should always be performed in conjunction with the 3D volume rendered reconstruction for a proper evaluation of dysmorphic or even dislocated structures such as the thyrohyoidal membrane or even the hyoid and thyroid—particularly if laryngeal fractures are present, which is also supported by recent literature[28] (Figure 4).

According to Berger et al asphyxia in hanging is detectable on PMCT by measuring the grey matter and white matter HU as well as the ratio of these.[29] The white matter brain tissue in asphyxia appears significantly more hypodense than in cases without asphyxia and/or intoxication.[29] However, the visual determination and additional Grey matter and white matter measurements of intoxication could not be used to reliably differentiate between the cases of intoxication and those with asphyxia.[29] Hence, for asphyxia, imaging already provides a diagnostic clue by measuring the HU of the brain tissue. The presence of the gas bubble sign would add another indicator for trauma to the neck leading to asphyxia and, when combined with traditional indicators, would potentially allow for a more precise PMCT imaging diagnosis of the cause of death and lead the examiner's focus to the assessment of the laryngeal skeleton.

## CONCLUSIONS

PMCT has proven to be essential in the evaluation of the larynx—not only for enhanced results in the detection rate of fractures but also for detecting gas bubbles within the soft tissue.[5,8] The complex evaluation of the larynx is profoundly supported by PMCT and the detection of the gas bubble sign as a diagnostic indicator for trauma to the neck in not putrefied cases. This relevant diagnostic finding might aid in not only post-mortem cases but also clinical cases of people who survive an assault to the neck.

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